Science of the Total Environment 621 (2018) 95–107

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Potential urban runoff impacts and contaminant distributions in shoreline and reservoir environments of Lake Havasu, southwestern United States

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HIGHLIGHTS

- Drainage mouth and water supply reservoir evaluated for stormwater runoff impacts
- Sediment grain-size and drainage mouth age affect some component concentrations.
- Noted shoreline to offshore sediment heavy metal trends not statistically upheld
- Pollution indices indicate no to minor sediment contamination.
- River/reservoir dynamics probably overshadow local stormwater component input.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 12 August 2017
Received in revised form 17 November 2017
Accepted 20 November 2017
Available online 23 November 2017

Editor: G. Ashantha Goonetilleke

Keywords:
Heavy metals
Nutrients
Flow-through reservoir
Pollution indices
Lake Havasu

ABSTRACT

Heavy metal, nutrient, and hydrocarbon levels in and adjacent to Lake Havasu, a regionally significant water supply reservoir with a highly controlled, dynamic flow regime, are assessed in relation to possible stormwater runoff impacts from an arid urban center. Shallow groundwater and sediment analyses from ephemeral drainage (wash) mouths that convey stormwater runoff from Lake Havasu City, Arizona to the reservoir, provided contaminant control points and correlation ties with the reservoir environment. Fine-grain sediments tend to contain higher heavy metal concentrations whereas nutrients are more evenly distributed, except low total organic carbon levels from young wash mouth surfaces devoid of vegetation. Heavy metal and total phosphate sediment concentrations in transects from wash mouths into the reservoir have mixed and decreasing trends, respectively. Both series may indicate chemical depositional influences from urban runoff, yet no statistically significant concentration differences occur between specific wash mouths and corresponding offshore transects. Heavy metal pollution indices of all sediments indicate no discernible to minor contamination, indicating that runoff impacts are minimal. Nevertheless, several heavy metal concentrations from mid-reservoir sediment sites increase southward through the length of the reservoir. Continual significant water flow through the reservoir may help to disperse locally derived runoff particulates, which could mix and settle down gradient with chemical loads from upriver sources and local atmospheric deposition. Incorporating the shoreline environment with the reservoir investigation provides spatial continuity in assessing contaminant sources and distribution patterns. This is particularly acute in the investigation of energetic, flow-through reservoirs in which sources may be overlooked if solely analyzing the reservoir environment.

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https://doi.org/10.1016/j.scitotenv.2017.11.223

1. Introduction

Chemical contaminants transported from anthropogenic sources into fluvial/lacustrine systems is an ongoing global process that has produced both local and widespread negative environmental impacts as these environments are considered contaminant carriers and sinks (Kanu and Achi, 2011; Weilenmann, and O'Melia, C. R., and Stumm, W., 1989). Proper watershed management of potential contaminant pathways into receiving waters is crucial to preventing or minimizing impacts. Urban stormwater runoff, in particular, can be a major contributor of chemical contaminants into reservoirs. Research has addressed this issue through various perspectives including comparing concentration levels with established pollution regulations or indices (Cevik et al., 2009; Rabee et al., 2011; Zarei et al., 2014), biological toxicity (Kirby et al., 2001; Widianarko et al., 2000), constituent distribution in suspended particulates and bottom sediments (Adiyiah et al., 2014; Chanudet and Filella, 2007; Stone and Walling, 1997), nature of chemical accumulation in sediments (e.g. adsorption, speciation; Bojakowska, 2016; Lin and Chen, 1998; Pradit et al., 2010), types of contaminant sources (Bai et al., 2011; Councell et al., 2004; Li et al., 2013), and to some extent, the hydrological dynamics of the reservoir (Kuriata-Potasznik et al., 2016; Rosen, 2015).

To the last point, many reservoirs are located on small stream systems with minor outflows and fairly low energy depositional settings (Bing et al., 2013; Skordas et al., 2015). Reservoirs on major rivers that receive and release significant flows (flow-through) for water supply deliveries to down river population or agricultural centers (Berg et al., 1995; Li et al., 2013; Karadede and Unlu, 2000) may experience higher energies resulting in more complex depositional patterns (Holdren and Turner, 2010). This dynamic affects the dispersal of suspended sediment and associated coagulated or adsorbed contaminants, whether from upriver or local stormwater runoff sources (Kuriata-Potasznik et al., 2016; O'Melia, 1998).

The above work has included a variety of land use sources of stormwater runoff varying from heavily industrialized to primarily agrarian in a variety of climates (Avila-Perez et al., 1999; El Bilali et al., 2002; Chen et al., 2014; Scheibye et al., 2014). Discussions of chemical pollution impacts in arid region reservoirs, regardless of their hydrology, have primarily focused on the suspended and bed load subaqueous sediments, as they provide an optimum medium to assess contaminant extent (Arain et al., 2008; El-Sayed et al., 2015; Goher et al., 2014; Wilson and Van Metre, 2000). However, there has been little inclusion of subaerial shoreline settings (Connell and Dreiss, 1995), particularly ephemeral drainage mouths where initial significant sediment deposition occurs during stormwater runoff events. Investigation of drainage mouth sediments with associated shallow groundwater at the reservoir shoreline, together with subaqueous sediments, may provide insights to stormwater runoff contaminant impacts and distributions.

The lower reaches of the Colorado River in the southwestern United States, one of the most regulated bodies of water in the world for water supply deliveries, includes a string of four reservoirs. Lake Havasu, the southernmost and smallest, is a pivotal reservoir between California and Arizona in one of the driest climates in North America and experiences significant flow-through water volumes (Fig. 1). Two water supply diversion points at the reservoir's southern end withdraw over 3 billion m^3 per year to over 25 million people in southern California and central Arizona. Outflows from Lake Havasu, via Parker Dam, are earmarked primarily for agricultural irrigation further south in Arizona, California and Mexico that supply >90% of winter leaf crops to the United States (Sanchez et al., 2005). This reservoir also receives intermittent urban stormwater runoff from Lake Havasu City that must inevitably intermix with inflowing Colorado River water. The impacts by contaminants, including heavy metals, nutrients, and hydrocarbons, contained in the runoff on Lake Havasu's environmental health are unknown. Public health is a primary management concern not only for water deliveries, but also the safety of millions of visitors that recreate on Lake Havasu each year. The purpose of this study is to determine chemical contamination levels and distribution on Lake Havasu shallow groundwater and sediments at drainage (wash) mouths and in reservoir sediments.

2. Materials and methods

2.1. Study area

Lake Havasu is a 7800 ha, 40 km long reservoir that averages 11 m deep with depths up 27 m along the drowned river thalweg (Fig. 1). Colorado River flows into the reservoir vary from 19 to 39 million m^3/day between the late fall and spring, reflecting seasonal irrigation demands in the area's extreme desert environment. Lake Havasu City, Arizona lies on the eastern shore of Lake Havasu and approximately 31 km north of the main water delivery diversion points near Parker Dam. Land use in the city is mostly residential/commercial with some light industrial manufacturing. Eleven major ephemeral drainages (herein called washes) covering 6800 ha in the city have been conveying stormwater runoff into the reservoir since the City's establishment in 1964. The geology within the drainage area consists of westward thickening Pliocene-Quaternary fanglomerates punctuated by exposures of Tertiary volcanic and granitic rocks and Proterozoic metamorphic rocks (Howard et al., 1999) that could act as chemical sources to mix with urban sources as stormwater runoff flows through the city toward the reservoir.

Wash mouths at the reservoir shoreline today were once an upslope reach of these washes prior to the reservoir's creation in 1939. Most consist of small deltas covered with abundant aquatic and terrestrial vegetation developed since that time. Exceptions occur at Pima, El Dorado, and a portion of Kiowa wash mouths where each experienced delta building from one 100–year flood event in July 2012 that effectively pinpoints the age of these wash mouth sediments. Sediment subaerially exposed at these three wash mouths consist of oxic, yellow-brown, unconsolidated silty to gravelly sand. This sediment type, when exposed at lower reservoir levels, fine-grained (v. fine sand, silt/clay) sediments at Daytona, Chemehuevi and Indian Peak wash mouths, and all reservoir sediments, contain a thin surficial oxic zone (2 mm–4 cm) underlain by a black anoxic zone of varying thickness. Bacterial decay of organic matter in low permeable, fine-grained sediment tends to produce anoxic conditions, reducing iron and manganese compounds that cause the black color (Gadd, 2010). Atmospheric exposure of the sampled sediment for a few hours oxidizes the iron and manganese, changing the sediment color to yellow-brown.

Sample sites in the study area occur onshore at wash mouths to analyze shallow groundwater and sediment, just offshore of wash mouths for reservoir surface water (Fig. 1), and at various locations throughout the reservoir for sediment analysis (Fig. 2). Surface water samples were collected primarily to substantiate other monitoring efforts (unpublished) that the reservoir chemistry is spatially consistent.

2.2. Reservoir surface water and wash mouth groundwater samples

Grab samples were collected by boat adjacent to wash mouths for reservoir surface water and from 30 to 60 cm deep dug pits, 0.6 to 7.5 m away from the shoreline for groundwater (Fig. 1). The distance from the shoreline depended in part on the slope of the land surface at the shoreline and on the reservoir level at the time of collection, which fluctuated between 135.6 and 137 m above mean sea level during the study period. Thick vegetative cover prohibited access via land or boat to Havasupai and Mockingbird wash mouths and severely limited access at five other wash mouths for collecting groundwater or sediment samples. The Daytona Wash location was on the side of the incised wash area, not within the channel proper. Kiowa, Industrial, Chemehuevi, and Indian Peak wash mouth surfaces were only accessible when the reservoir level was below136 m elevation.